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14. ABSTRACT Marksmanship accuracy and sighting time were quantified with 62 male trainees during Navy SEAL Hell Week, which involves the combined stress of sleep loss, operational combat scenarios, and cold-wet environmental conditions. Volunteers used a marksmanship simulator system to measure shooting speed and accuracy. Marksmanship was assessed prior to training, and at 73 and 80 h into Hell Week. Volunteers randomly received either 100, 200, or 300 mg of caffeine or a placebo 72 h after training commenced. The combined effects of almost 73 h of total sleep deprivation degraded all marksmanship accuracy measures ($p < 0.05$); i.e., 37.5% increase in targets missed, 38% increase in distance from center of mass of the target, and the 235% increase in shot group tightness. Sighting time increased by 53% or 3.1 sec after 73 h of sleep deprivation ($p < 0.05$). Sighting time was significantly faster after taking 200 or 300 mg of caffeine compared with placebo or 100 mg of caffeine. Caffeine (200 or 300 mg) enabled SEAL trainees to sight the target and pull the trigger faster without compromising shooting accuracy during this sustained operation.						
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Caffeine Effects on Marksmanship During High-Stress Military Training with 72 Hour Sleep Deprivation

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Purpose: Navy SEALs (sea, air, land) are elite special warfare units that conduct unconventional warfare primarily in marine environments. Marksmanship accuracy and sighting time were quantified with 62 male trainees during Navy SEAL Hell Week, which involves the combined stress of sleep loss, operational combat scenarios, and cold-wet environmental conditions. Caffeine was administered to minimize deficits due to sleep deprivation. **Methods:** Volunteers dry-fired a disabled rifle equipped with a laser-based marksmanship simulator system to measure shooting speed and accuracy. The target was a 2.3-cm diameter circle at a distance of 5 m, simulating a 46 cm target at a distance of 50 m. Marksmanship was assessed prior to training, and at 73 and 80 h into Hell Week. Volunteers were randomly assigned to 1 of 4 treatments: 100, 200, or 300 mg of caffeine or a placebo. Dosing occurred 72 h after training commenced. **Results:** The combined effects of almost 73 h of total sleep deprivation and operational and environmental stress degraded all marksmanship accuracy measures ($p < 0.05$) as shown by the 37.5% increase in percent of targets missed, 38% increase in distance from center of mass of the target, and the 235% increase in shot group tightness. Sighting time increased by 53% or 3.1 s after 73 h of sleep deprivation ($p < 0.05$). Sighting time was significantly faster in sleep deprived individuals after taking 200 or 300 mg of caffeine compared with placebo or 100 mg of caffeine. No differences in accuracy measures between caffeine treatment groups were evident at any test period. **Conclusion:** During periods of sleep deprivation combined with other stressors, the use of 200 or 300 mg of caffeine enabled SEAL trainees to sight the target and pull the trigger faster without compromising shooting accuracy.

Keywords: sleep deprivation, caffeine, marksmanship, rifle shooting, environmental stress, steadiness, combat stress, Navy SEALs, military training, coordination, motor performance.

NAVY SEALs (SEA, AIR, LAND) are elite special warfare units that conduct unconventional warfare primarily in marine environments. Navy SEALs may engage in continuous combat operations for periods exceeding 24 h, often under the cover of darkness at night and in the early morning hours. Shooting accurately is a critical task for SEALs and other military personnel. Previous research has demonstrated that environmental stress such as high altitude and heat impair shooting accuracy (7,15). Sleep deprivation causes a significant decrease in marksmanship accuracy and increases time to sight the target (5). Haslam (5) reported that infantrymen shooting in the prone position hit 25% fewer pop-up targets when deprived of sleep longer than 48 h. When sleep deprived for 90 h, there

was no deterioration in accuracy when shooting at a stationary target with no time constraint, but shooting was 10% worse compared with baseline levels when targets appeared at random locations on a firing range (6). Competitive shooters have also shown degradations in shooting performance due to the effects of sleep deprivation and circadian desynchronization associated with time zone shifts when traveling to international competitions (1). In previous research, shooting performance on the first night without sleep was relatively accurate, but with continued sleep deprivation, performance deteriorated coinciding with the troughs in circadian rhythms of alertness with performance degraded most between midnight and 0500 h (1).

Caffeine has stimulant-like effects when administered in moderate doses, improving alertness and performance on tasks that contain a vigilance component (2,10). While sleep deprived, caffeine ingestion may improve some cognitive tasks (13,14). Research on the use of caffeine and marksmanship has focused on the possible beneficial effects of caffeine use by non-sleep deprived soldiers performing simulated sentry duty where the volunteer had to detect infrequent (12 per 30 min), brief (3 to 6 s) targets (7,8). These studies were patterned after Mackworth's (11) classic work on vigilance. Performance on the sentry duty task improved because vigilance was enhanced as a result of the administration of 200 mg of caffeine. There were no changes in shooting accuracy in these two studies. When volunteers were required to identify a friend vs. a foe for 3 h, 200 mg of caffeine increased correct identifications as time progressed (9). No previous research has examined the ability of caffeine to minimize

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the detrimental effects of sleep deprivation on rifle marksmanship.

The purpose of this research was to determine if supplemental caffeine could sustain rifle marksmanship performance in sleep deprived individuals subjected to combat-like stress. Three doses of caffeine (100 mg, 200 mg, and 300 mg) were administered to determine the optimal dose, if any, to maintain performance. Testing was done during Hell Week of SEAL training.

METHODS

Subjects and Experimental Design

This study was part of a larger study examining cognitive function conducted at the Naval Special Warfare Training Center in Coronado, CA. To become a Navy SEAL, an individual has to complete the Basic Underwater Demolition/SEAL (BUD/S) program. The sixth week of the program involves intense around-the-clock training with very little sleep and is known as Hell Week. Attrition is the highest this week compared with any other single week during BUD/S training. This study was conducted during Hell Week because it simulates the combat-like stress conditions Navy SEALs may experience. The volunteers of this study were 62 members of a BUD/S class. There were 16 volunteers in each of the caffeine groups and 14 in the placebo group. The experiment was approved by the appropriate Institutional Scientific and Human Use Review Committees. The subjects were briefed on the study procedures, and written consent was obtained from each volunteer before study participation. Each volunteer was informed of the right to withdraw from the study without prejudice at any time. All volunteers were men because women are not admitted into the Navy SEAL program.

SEAL trainees averaged (mean \pm SEM) 24 ± 0.3 yr of age, weighed 77.1 ± 1.0 kg, and had an average height of 177.3 ± 0.9 cm prior to the start of Hell Week. They had 2.9 ± 0.3 yr prior military service and the majority were Caucasian. Of the volunteers, 27% were officers with the remainder being enlisted personnel. Most (72%) had prior recreational marksmanship experience, but few (21%) were military qualified marksmen. During Navy Basic Training, recruits are provided with weapons training but it is on a simulator system, similar to the one used on this study, not with live weapons on a live range. Many are not officially qualified as marksmen. In addition, Navy SEAL small arms training takes place in the third phase of BUD/S training approximately 10 wk after Hell Week because the cost is greater for weapons training than basic conditioning. Higher level training such as marksmanship training is only provided to those candidates that pass the more basic level fitness training. On average, volunteers reported getting 6.9 ± 0.1 h of sleep/night prior to Hell Week training. No significant differences in any demographic characteristics existed between treatment groups.

Prior to Hell Week, volunteers received marksmanship training using the rifle marksmanship simulator, and their saliva caffeine levels were assessed. At 2100 h on a Sunday night, SEAL trainees were awakened from

sleep in their living quarters to begin their Hell Week training. This training was physically demanding and included such tasks as running, lifting, swimming, calisthenics and paddling of life rafts. The following Wednesday night, at approximately 2100 h, caffeine or placebo was administered. At the time of dosing, volunteers had been allowed a total of 1.5 h of sleep since beginning Hell Week, 72 h earlier. This sleep occurred approximately 15 h prior to dosing. The trainees (volunteers and non-volunteers) were not permitted to consume coffee, or other caffeine-containing beverages or foods, to smoke, or to have any personal food during Hell Week. This restriction on caffeine is consistent with normal policy regarding caffeine during SEAL Hell Week training. Information obtained on a self-report questionnaire revealed that most volunteers were non-coffee drinkers and consumed moderate levels of caffeine primarily through caffeinated soft drinks, with the majority of trainees consuming one to two 12 ounce containers of soda (approximately 40–100 mg) per day.

There were four treatment groups. Volunteers were randomly assigned to one of three caffeine doses (100 mg, 200 mg, or 300 mg) or a placebo, all in pill form. The number of pills taken and the physical characteristics of the pills were identical between groups to ensure double-blind administration. Volunteers continued regular training exercises for about an hour after caffeine or placebo ingestion, and then marksmanship performance was assessed and a saliva sample obtained. This testing occurred 73 h into Hell Week. After an hour of testing, which included a battery of psychological tests in addition to the marksmanship assessment, volunteers resumed regular BUD/S training. At about 8 h (80 h into Hell Week) after caffeine/placebo ingestion, volunteers provided another saliva sample and marksmanship was assessed again.

Salivary Caffeine Level

Caffeine levels were assessed using saliva samples. This methodology has been previously validated in several studies (12,18). Volunteers provided 10 ml samples of saliva on four different occasions by chewing on a cotton swab to absorb the saliva, which was then deposited into a special centrifuge tube (Sarstedt; Newton, NC). Saliva samples were obtained for caffeine analyses: 1) once prior to Hell Week; 2) immediately prior to caffeine/placebo ingestion; 3) 1 h after caffeine/placebo ingestion (time of peak level of caffeine in plasma); and 4) about 8 h after caffeine/placebo ingestion with the half-life of caffeine in the plasma to be 4–5 h (16). Four volunteers, three in the 200 mg caffeine group and one in the 300 mg caffeine group did not provide saliva samples, reflecting differences in sample sizes. The samples were frozen and shipped to the Pennington Biomedical Research Center for analysis. Samples were analyzed on the Beckman Synchron CX5 using EMIT reagents for caffeine (Dade-Behring Diagnostics, Deerfield, IL). The assay is based on competition for antibody binding sites between caffeine in the sample and caffeine labeled with the enzyme glucose-6-phosphate dehydrogenase.

TABLE I. SALIVARY LEVELS OF CAFFEINE OVER TIME BY TREATMENT GROUP.

Salivary Caffeine Levels	Placebo (n = 14)	100 mg (n = 16)	200 mg (n = 13)	300 mg (n = 15)
Baseline ($\mu\text{g} \cdot \text{ml}^{-1}$)	$0.51 \pm 0.15^{\text{a1}}$	$0.60 \pm 0.16^{\text{a1}}$	$0.66 \pm 0.19^{\text{a1}}$	$0.59 \pm 0.14^{\text{a1}}$
Immediate pre-dosing ($\mu\text{g} \cdot \text{ml}^{-1}$)	$0.46 \pm 0.08^{\text{a1}}$	$0.54 \pm 0.08^{\text{a1}}$	$0.62 \pm 0.14^{\text{a1}}$	$0.59 \pm 0.11^{\text{a1}}$
1 hour post-dosing ($\mu\text{g} \cdot \text{ml}^{-1}$)	$0.43 \pm 0.07^{\text{a1}}$	$1.59 \pm 0.05^{\text{b3}}$	$2.94 \pm 0.18^{\text{c3}}$	$4.31 \pm 0.17^{\text{d3}}$
8 hours post-dosing ($\mu\text{g} \cdot \text{ml}^{-1}$)	$0.51 \pm 0.07^{\text{a1}}$	$1.03 \pm 0.13^{\text{b2}}$	$1.32 \pm 0.13^{\text{b2}}$	$2.40 \pm 0.22^{\text{c2}}$

* Values with different superscript letters are different from each other across dosing groups (across a row) while values with different superscript numbers are different from each other over time (within a column) using least significant difference tests at $p < 0.05$.

Marksmanship Assessment

Rifle marksmanship was quantified with a laser marksmanship simulator system (Noptel ST-1000, Noptel, Oy, Oulu, Finland). The system consists of a laser transmitter, an optical glass laser-sensitive receiver with an associated paper aiming target, a personal computer, a printer, manufacturer supplied software, and a disabled AK-47 rifle. The laser transmitter emits a continuous 0.55 mm, 0.8 μm wavelength beam, which is invisible to the eye, and allows aiming positions to be monitored and recorded throughout the sighting and shooting process. A vibration sensor in the laser detects when the weapon is dry-fired, i.e., firing the weapon without a bullet in the chamber. Shot location of the laser is recorded via its position on the optical glass laser sensor. The target was a 2.3-cm diameter circle located 5 m away. This simulates a 46-cm diameter target at 50 m, which is similar to the standard 49 cm wide "100 m military silhouette man target" used on training and qualifying ranges for the U.S. Army.

Volunteers were tested for marksmanship accuracy and speed. There were three accuracy measures: 1) the distance from center of mass of the target (DCM); 2) shot group tightness (SGT); and 3) percent of targets missed. DCM is calculated in mm by determining the average shot location away from the center of the target and determining the distance from that location to the center of mass of the target. SGT is the area in mm^2 of the shot group; i.e., the maximum horizontal distance multiplied by the maximum vertical distance between shots. This measure is actually a measure of shot dispersion rather than accuracy because it is calculated without regard to the closeness to the center of the target. However, those shooters that have a tight shot group have an easier time of shooting accurately because they shoot consistently. Adjustment of the weapon's sights would allow those with a tight shot group to shoot more accurately than an individual who has a more disperse shot group. Percent of targets missed are the number of targets missed divided by the total number of targets shot at. To obtain measures of DCM and SGT when a target was missed completely, the individual shot was given a location on the target as far away from the target center in the direction the shot missed the target. Hence, DCM and SGT reported are actually smaller than the true but unmeasurable deviations.

During assessment, volunteers lay prone using sandbags for support. Following a ready signal and a 1–10 s (randomly varied) preparatory interval, a red LED light positioned 16 cm to the lower left of the target was illuminated as the signal to shoot. The volunteer then

fired at the target as quickly as possible while trying to maintain accuracy. A total of 8 shots or trials were taken per assessment (a trial consisted of waiting for the light, sighting the target, and pulling the trigger vs. firing multiple shots on illumination of the red stimulus light). There was one speed measurement, sighting time which was measured electronically using the internal clock of the computer to which the laser system was attached. Sighting time was the time in seconds from the illumination of the red stimulus light to the time the trigger was pulled. Marksmanship measures were assessed in two groups of four shots each and then averaged for each marksmanship assessment period.

Statistical Analyses

Descriptive statistics are presented as means and standard errors in the text, tables, and figures. One-way repeated measures analyses of variance (ANOVAs) were performed using just the placebo group's data on each rifle marksmanship measure to assess the effects of Hell Week. Two-way repeated measures ANOVA with time (baseline, 73 h and 80 h into Hell Week) as the within factor and dose level as the grouping variable were performed on each marksmanship measure. To isolate the effects of caffeine, using caffeine dose level as a grouping factor, analyses of covariance (ANCOVA) with baseline measures used as the covariate to correct for baseline differences were also performed for each marksmanship measure for the 1 and 8 h post-dosing sessions. A Bonferroni adjustment was made to control for running multiple ANOVAs and ANCOVAs. A repeated measures (time) ANOVA with a grouping factor (caffeine dose) was conducted on caffeine concentrations using the saliva assays. Post hoc, least significant difference tests were used to isolate differences between groups and over time ($p < 0.05$) when a significant F-test existed.

RESULTS

Salivary caffeine levels by dose are shown in Table I. No differences in baseline or pre-dosing levels measured during Hell Week existed between groups. At 1 h after dosing, as expected, a significant dose response effect occurred ($p < 0.05$). By 8 h after dosing, those administered caffeine still showed elevated salivary caffeine concentrations ($p < 0.05$), although no significant difference was observed between the 100 mg and 200 mg groups. A significant time effect was also present except for the placebo group, with the highest salivary concentrations occurring 1 h after dosing. Eight hours

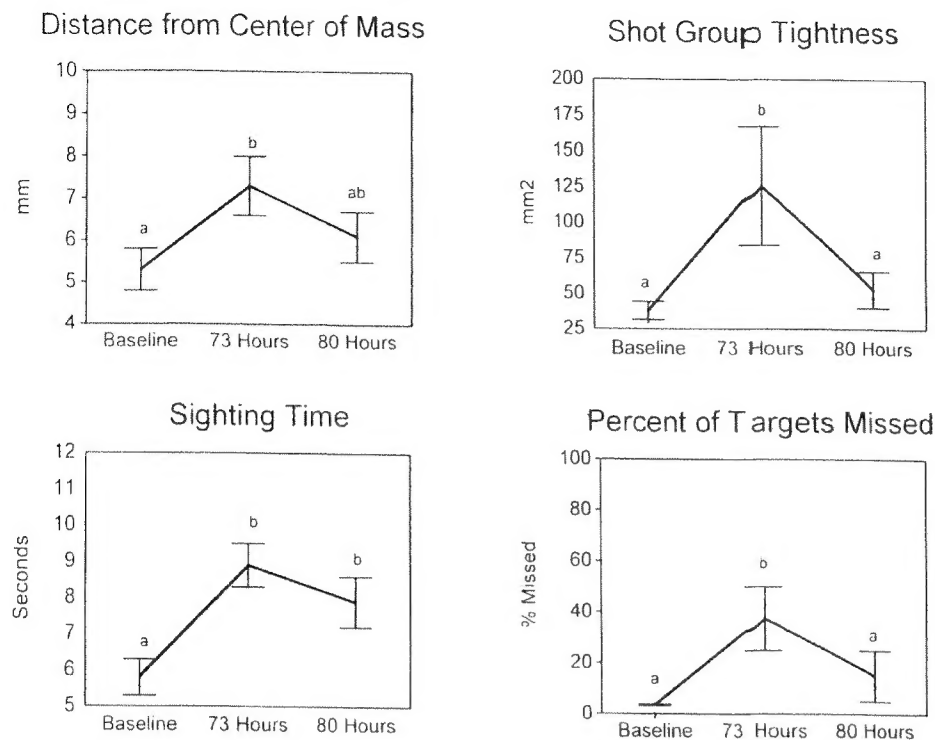


Fig. 1. SEAL training effects on measures of marksmanship accuracy and speed using placebo data only. Values with different letters are different from each other using least significant difference test at $p < 0.05$.

after dosing, caffeine levels were lower than at 1 h, but still elevated.

All marksmanship measures were significantly ($p < 0.05$) impaired in the placebo group 73 h into Hell Week compared with their baseline measures (Fig. 1). Decrements included DCM increasing by 38% and SGT increasing 235%, with an increase of 37.5% more targets missed. Sighting time increased by 53% or 3.1 s. At approximately 80 h into Hell Week, all marksmanship measures improved somewhat compared with the 73 h assessment. From Fig. 1, note the downward lines representing a smaller distance away from target center (DCM), a smaller dispersion of shots (SGT), less time needed to sight the target (sighting time), and smaller percent of targets missed. However the improvement was only significant for SGT and percent of targets missed. The three accuracy measures (DCM, SGT, and percent of targets missed) were not significantly different from baseline. However, DCM at the 80-h test period was also not different from the 73-h value either. Sighting time was significantly longer at the 80-h test period compared with baseline, but did not differ significantly from the time observed at the 73-h test period ($p < 0.05$). Results from the two-way ANOVAs show no group or interaction differences but significant effects of time ($p < 0.05$) were observed for all four measures. These differences were similar to that found with the placebo group alone, except that the impairments were less, but not significantly less, over time when caffeine groups were included.

No differences in marksmanship accuracy existed between treatment groups at either 1 h or 8 h post-dosing (Fig. 2). Sighting time was significantly shorter for the 200 mg and 300 mg caffeine groups at both 1 h and 8 h after dosing. Those receiving 200 mg of caffeine had

shorter sighting times at 1 h after dosing, while those receiving 300 mg of caffeine sighting times were the shortest 8 h after dosing. The 200 mg caffeine group had a 30% tighter shot group while their sighting times were 0.8 s faster compared with the placebo group 1 h after dosing.

DISCUSSION

The combined stress of sleep deprivation, operational stress (fatigue imposed by training and psychological demands imposed by instructors), environmental stress (cold and wet from ocean training), and circadian effects contributed to the decrements in performance in both shooting accuracy and time to sight and fire at the target as indicated by changes in marksmanship of the placebo group. Caffeine treatment appears to mitigate these effects. Using two-way repeated ANOVAs, main effects of caffeine or caffeine by time interaction effects were not significant because the effects of the stress imposed by Hell Week and the intersubject variability were too great relative to the mitigating effects of caffeine to detect drug level differences. However, using subsequent ANCOVAs at the two different time periods (1 h post-caffeine administration and 8 h post-caffeine administration) while controlling for baseline individual differences showed that sighting time was faster at 73 h into Hell Week, after taking either 200 mg or 300 mg of caffeine compared with placebo or 100 mg of caffeine, while caffeine had no effect on shooting accuracy. Bonferroni's adjustment was made to minimize Type I error associated with running multiple analyses. These results are similar to those of Johnson et al. (7,8) who reported that the use of 200 mg of caffeine in a sentry duty paradigm did not improve marksmanship.

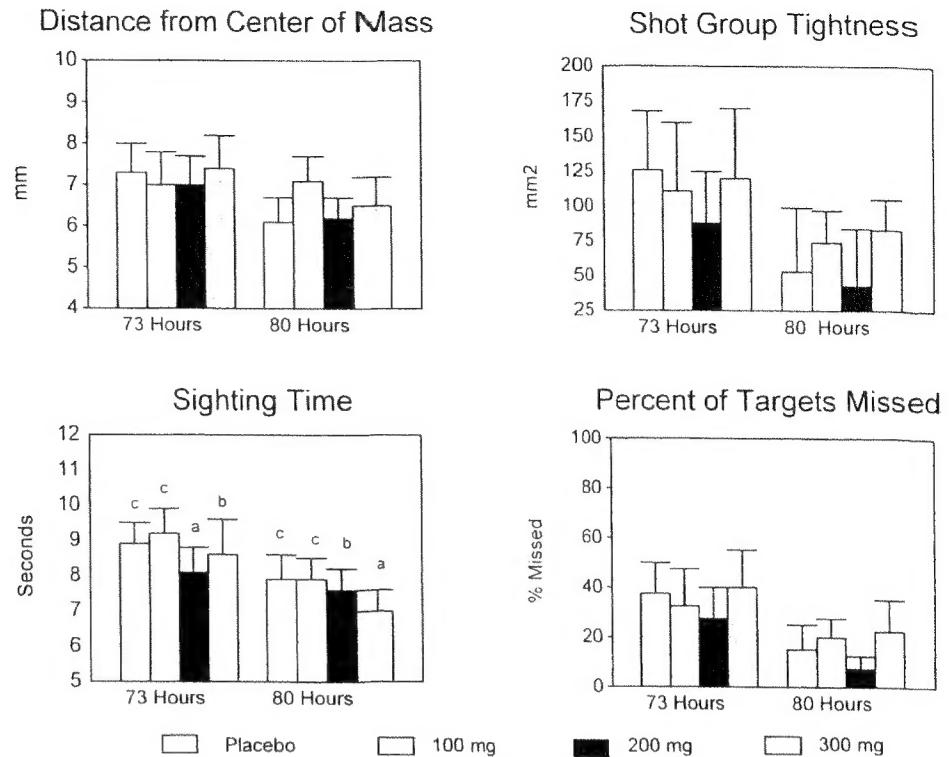


Fig. 2. Effects of caffeine dose on measures of marksmanship accuracy and speed 73 and 80 h into SEAL Hell Week. Values with different letters are different from each other using least significant difference test at $p < 0.05$.

ship accuracy (total targets hit), but did improve target detection time. However, the studies reported by Johnson et al. (7,8) used brief and infrequent stimuli to simulate conditions that would be encountered during sentry duty. In the present investigation, test conditions were intended to simulate a more "active" combat-like environment; thus, a target was presented to the shooter on average once every 30 s at a simulated distance of 50 m. Furthermore, the volunteers in our study experienced the effects of sleep deprivation and other operational stressors.

A dose of 200 mg of caffeine was more effective at improving sighting time than the 300 mg dose at 1 h after ingestion. All measures of shooting accuracy (DCM, SGT, and percent of targets missed) were affected similarly by consuming 200 mg compared with 300 mg of caffeine. Therefore, 200 mg is the optimal dose for marksmanship since there was a dose response effect when compared with the placebo or 100 mg dosings. The 300 mg dose while effective, may impair some functions like steadiness or lead to other unwanted side effects (10). Despite the apparent lack of any marksmanship advantage of taking the higher dose of caffeine during the first hour following consumption, sighting time scores 8 h after caffeine ingestion show that 300 mg dose was more effective than 200 mg for that measure. Salivary levels of caffeine in the 200 mg caffeine group at 1 h and the 300 mg caffeine group at 8 h are relatively similar ($2.94 \mu\text{g} \cdot \text{ml}^{-1}$ vs. $2.40 \mu\text{g} \cdot \text{ml}^{-1}$). This suggests that a dose of 200 mg of caffeine is sufficient for an acute effect on marksmanship, but 300 mg of caffeine will enhance performance for a longer period (up to 8 h). Future studies should consider whether re-dosing with 200 mg of caffeine may be preferable to consuming

single doses of caffeine exceeding 200 mg when marksmanship must be sustained in sleep deprived individuals for extended periods. The data from this study indicate that beneficial effects produced by caffeine ingestion on marksmanship performance can persist for at least 8 h.

Some of the improvements in marksmanship at 8 h after dosing (80 h of sleep deprivation) compared with the 1 h after dosing time period are likely the result of the testing taking place after the sun had risen, with increases in body temperature (3), and improved psychological well-being or cognitive improvements. Related research by Fröberg et al. (4) showed that once sleep deprived, marksmanship performance is likely to follow circadian cycling with late night and early morning performance degraded to a greater extent than performance during daylight hours. Even though the second session occurred between 0500 and 0600 h, not the peak of circadian alertness, the nadir of the circadian cycle had most likely passed. Future research on sleep deprivation effects on marksmanship and potential supplements to reduce these decrements should probably incorporate the assessment of marksmanship at several time periods corresponding to circadian nadirs and zeniths. Previous research with an auditory vigilance task showed that performance effects were maintained above placebo levels 24 h later when presumably the effects of caffeine should have worn off (17). They suggest that residual caffeine in the system or that administration of caffeine altered the circadian rhythm of sleepiness/alertness. These explanations may also explain the positive results with marksmanship performance in this study 8 h after being administered 200 mg or 300 mg of caffeine.

In summary, improving time to sight the target and pull the trigger while not impairing accuracy is important for a combat soldier, Marine, or Navy SEAL who is deprived of sleep, but who must still maintain proficiency in the use of small arms. These results show that caffeine may have a beneficial effect for rifle marksmanship during periods of sleep deprivation combined with other operational and environmental stressors.

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